DIGITAL Journal

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BULLETIN

The FCC rule making proposal on 15 June granted the ARRL and the ADRS what they asked. When finalized, and there is no apparent opposition, the new rules will 1) end the HF packet STA, and 2) move fully automatic operators, regardless of HF mode, into legally defined segments of each band and c) permit semi-automatic stations to operate on any frequency where digital modes are allowed. The FCC said, "... we firmly believe that government should be responsive to user needs." And this sweeping decision confirms their attitude.

The Commission "was gratified by the cooperation and dedication of these two organizations within the amateur community in determining the conditions necessary to make these changes..."

(See the September issue for a full exploration of this significant rule making procedure.)

THE NEW MODES . . . CLOVER, G-TOR, PACTOR . . . WHICH ONE'S FOR YOU???

Pity the poor CW operators. This old mode requires little but a decision as to the type of input device. Should it be the straight key, the bug, the paddle or the computer today? Pity the poor SSB fans. Unchanged since the switch from AM, only the size, complexity and price of the black box differ from the original gear. Shall it be the with or without the amplifier today?

Pity the poor digital operator who today faces more challenges and decisions than a five-year-old squeezing a nickel in a penny candy store. New modes, new users and new methods saturate the traditional digital spectrum. Longtime keyboard relationships shatter as one partner or the other migrates from the old to the new. Tradition suffers a broken heart as progress, in the form of unrecognizable sounds sweeps across the bands. And the whispers and the shouting about intolerable conditions on the digital bands can be heard wherever we congregate.

Don't be fooled. Don't fall for the rumors that abound. Don't fall behind the pack. For this seeming chaos and confusion creates the elements of progress and the path to ever better digital communication. And it is this sort of experimentation that amateur radio is all about. This is the year, the summer, the month, the time - - take part in the revolution. Discover even more satisfying ways to utilize your digital skills.

What is next? Will it be the simplicity and promise of G-TOR? The dazzle of Pactor II? The unknown new mode yet to be announced? Only time will tell. Meanwhile, we suffer from a panoply of riches. No other phase of amateur activity even approaches our fabulous array of choices. Read, think and decide, then enjoy the experience of adding one or two or even three modes to your portfolio. There are no losers among the options on this agenda. Expand your horizons now. Master a new mode this very summer. You will never regret it.

Our special thanks to the three distinguished gentlemen who fill this special issue with their propietary view of our digital universe. Their support for this project and generous gift of their time is deeply appreciated. So to Phil, Bill and Tom, kudos for a splendid developmental effort and this exploration of their potential.

73 de Jim N2HOS

POSTMASTER

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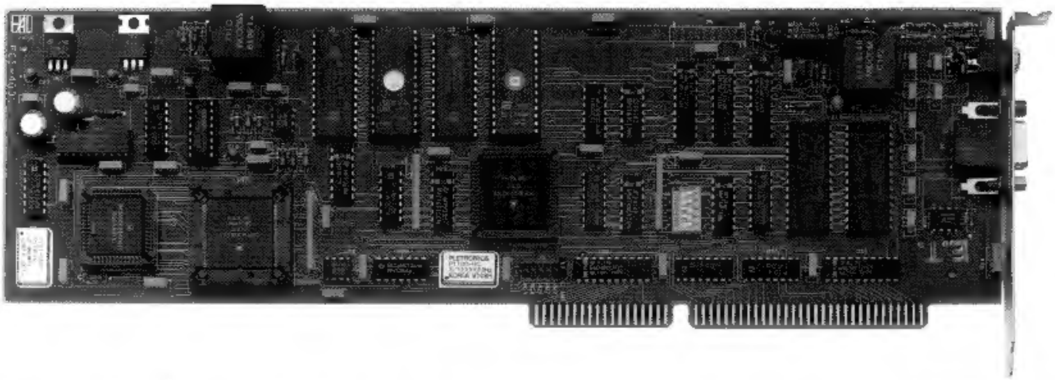

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The Case for CLOVER

Bill Henry, K9GWT[†]

I've been asked to write a few words about CLOVER - a few words about why I believe it is better than the "other modes". Well, let's get all the cards on the table. First - Pactor and G-TOR are the "other modes." Second - I'm biased. HAL and I have a lot invested in CLOVER. I'm not about to knock what pays the bills. Third, I don't intend to take "pot shots" at the competition. The Pactor and G-TOR fellows are no dummies. They both have modes that work well. BUT - when comparing CLOVER to these other modes, there is a very clear-cut difference in on-the-air performance. Let's discuss those differences.

CLOVER and then CLOVER-II were born out of years of frustration with AMTOR and AX.25 packet radio. AMTOR works well on HF circuits but is so slow that it's like watching grass grow. AX.25 really doesn't work right on HF circuits and is often even slower than AMTOR - like ZERO words-per-minute! But, AX.25 at least will send ASCII and even binary data - when conditions are perfect. Independently, Ray Petit, W7GHM, Jim Tolar, W8KOB, me, and quite a few other folks looked at the AMTOR / AX.25 problem and thought "there has to be a better way." Our initial goal was to "fix" packet so that it worked as well as AMTOR - but faster. As our tests and studies continued, it became more and more apparent that while FSK modulation and AX.25 protocol were ideal for VHF radio, most of packet's good VHF features turned out to cause serious problems when used on HF radio circuits.

Over a five year period, a totally new modulation format and data protocol were invented, based on what *will* work on HF. We call it "CLOVER." CLOVER was born out of a study of the questions:

- 1. Why don't "standard" data modes work better on HF?
- 2. What combination of modulation and protocol *will* work on HF?

What has evolved is without doubt a very complicated - and sophisticated - mode. CLOVER *requires* heavy-duty computer processing - a fast DSP is essential. A $1.00 Z-80 or 6809 just "ain't gonna make the grade." This leads to the present contradiction for CLOVER - it's got the best performance - and also the highest price. Due to limited production demand and some rather curious marketing strategies by the IC companies, the cost of DSP technology is still pretty high. DSP IC prices will *eventually* come down - but it's taking a lot longer than for other technologies. On the positive side, I think CLOVER has a lot to offer - more than any other HF data waveform, in fact.

First of all, look at "speed" or, more properly, "data throughput." Under typical HF conditions, CLOVER is 2 to 10 times faster than other data modes on HF. Comparison plots of the measured data throughput vs signal-to-noise (S/N) are shown in Figure 1. On a typical HF circuit, CLOVER data will really "scream" through the ether. AMTOR and Pactor do well on weak signals, but the more common situation on the HF bands is to have strong signals with the S/N ratio well over 10 or even 20 dB most of the time. AMTOR and Pactor throughput performance "flattens-out" above 5 dB S/N, wasting available "channel capacity" much of the time. While CLOVER's weak-signal performance is outstanding, it's the ability to take rapid advantage of those fleeting minutes - and hours - of good propagation that really tells the tale when you have lots of data to pass error free. Only CLOVER "keeps on going" and takes full advantage of real-time conditions.

A word about throughput measurements. All tests were made on the PCI-4000/M using the same test set-up. The test noise source is a DSP generator with a noise bandwidth of 3000 Hz. This is the standard CCIR bandwidth for such measurements; beware of tests run with narrower noise sources - the modem will look better than it really is. All throughput measurements were made using the same alphanumeric text stream - and - *with compression turned off*. Compression is great but all compression algorithms are very context sensitive. Each of us manufacturers can easily dream-up special test messages that make our modems look super-great - but that hardly leads to a fair comparison of modulation and protocols. Finally, data throughput is measured in terms of the "delivered element" - characters or bytes of data. Engineers like to talk about "bits-per-second", but

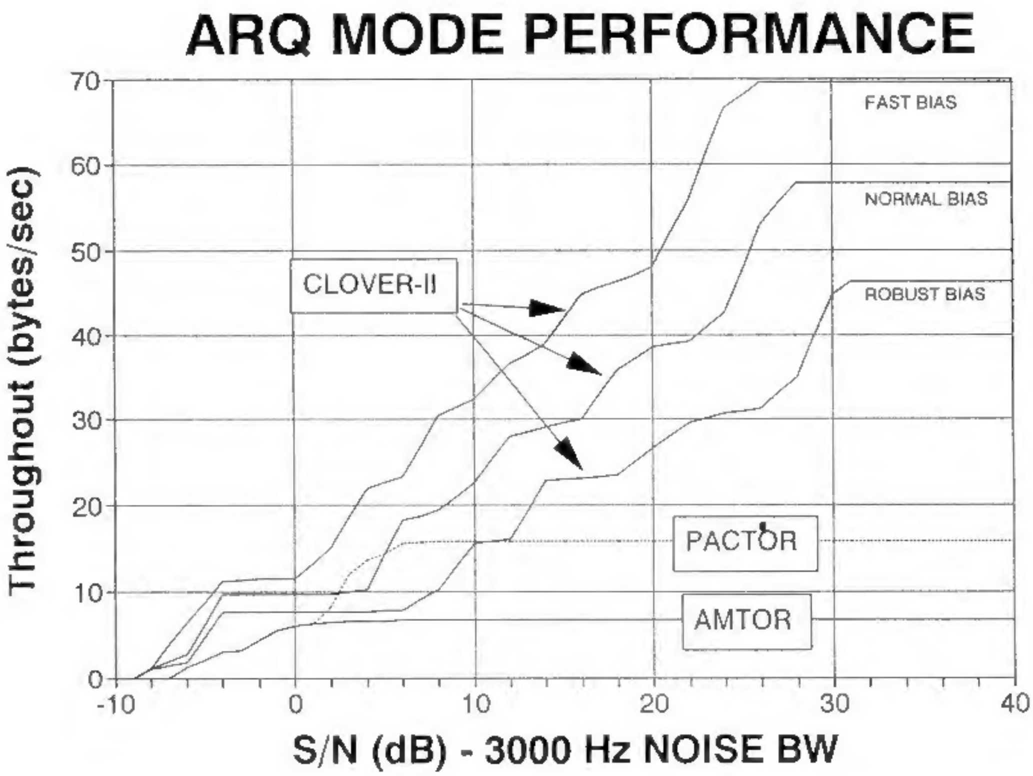

Figure 1

it's really characters (or bytes) that we see marching across the screen and it's how quickly we fill the screen (or a disk file) that gives us a sense of "speed."

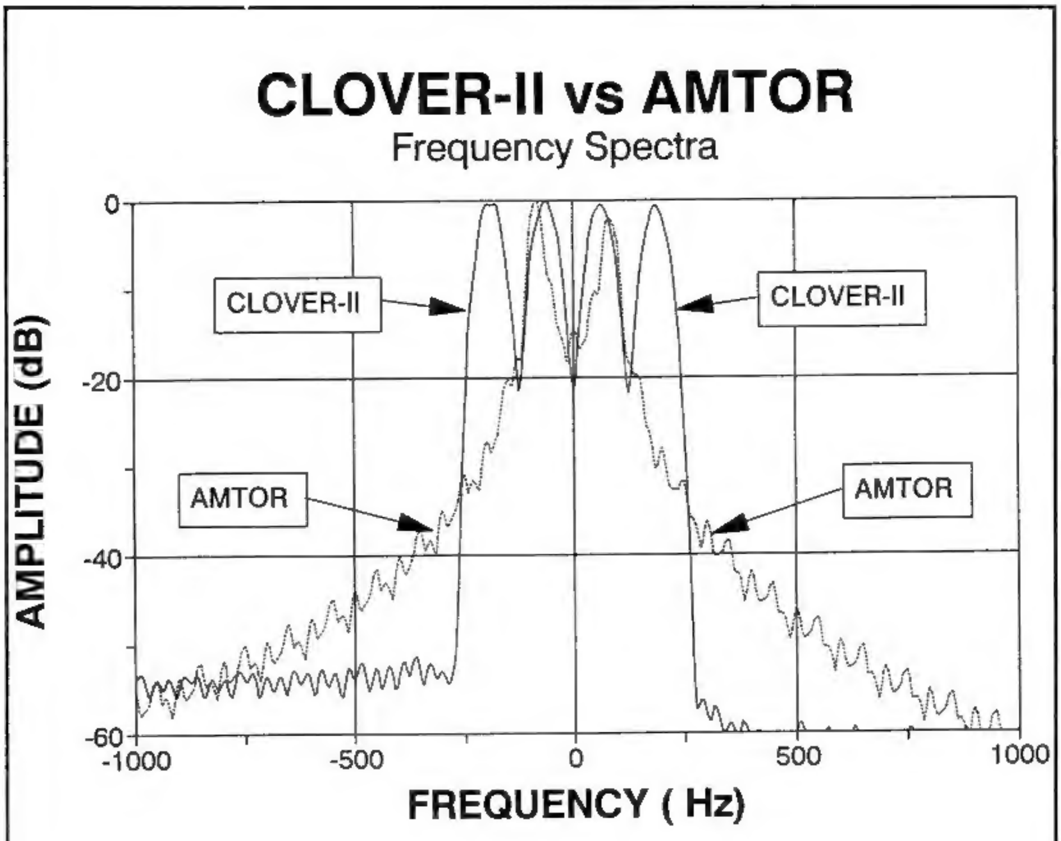

Figure 2

Second, CLOVER is continuously adaptive. CLOVER is the only mode that dynamically measures Signal-to-Noise ratio (SNR), phase dispersion (PHS) and error corrector loading (ECC) - AND - *directly adjusts* the modulation format to fit the real-time conditions. PACTOR, and G-TOR *don't* do that. Rather, these modes look at errors ("hits"), say "gee we haven't had many hits lets try a faster rate", or "Wow! Lot's of hits, better slow-down." That works, but it's kind of the same thing as closing the door well after the horse has skipped town. Only CLOVER actually measures the real ionosphere conditions and directly sets the modulation to a mode that *will* work. I contrast this to the other schemes which evolve to a philosophy of "let's make a change and see if it will work." I call this "by-guess-and-by-golly" adaptive control. Sometimes it works, but often the equipment spends a lot of time shifting gears - and little time actually passing traffic.

Third, CLOVER modulation is specifically tailored to combat HF distortion. The "symbol rate" (basic modulation switching rate) is intentionally slow - 31.25 symbols per second. By contrast, Pactor uses 100 and 200 baud; G-TOR 100, 200, and even 300 baud. The effects of multipath distortion have been well documented since the 1950's. Multipath time dispersion often exceeds 2 to 4 milliseconds. At 100 baud, each data pulse is 10 ms wide; 2-4 ms of time jitter will cause hits. At 200 baud, each pulse is only 5 ms wide and most will be destroyed by 2-4 ms of multipath time smearing. 300 baud? Well, try HF packet radio sometime - you'll see. Sometimes it actually works; more often, 300 baud throughput is slower than AMTOR. This is *not* progress! If you really want to design an HF mode that *always* works, you *don't* build-in a high symbol-rate handicap! While simple 2-tone FSK was great for RTTY in the 1940's, there are *much* more efficient and reliable ways to modulate your radio signal in 1994.

Fourth, CLOVER uses ARQ *and* error-correction coding. This means that many transmission errors are fixed by the modem *without requiring a repeat transmission.* In addition, when errors exceed the capacity of the error corrector, only the "damaged" data blocks are repeated - not every block as in AMTOR or Pactor or every block following the blown block as in packet. The CLOVER protocol is designed to produce the highest data throughput possible under all HF conditions.

Fifth, CLOVER-II is bi-directional and *you don't need an "OVER" command.* Send data any time you wish, even when the other station is sending. The CLOVER protocol sorts it out and keeps going. Also, *both* directions are independently auto-adaptive. Bad noise or interference at my station may slow down your transmissions, but if you receive my signal well, data from me to you will fly. No other HF data mode has this feature. Forget about OVER, MASTER, SLAVE, ISS, IRS and all the rest of the "ARQ alphabet soup." Just type.

Sixth, CLOVER is "code transparent." It sends all 8 bits just the way they come from your PC keyboard or disk file. AMTOR cannot do this; TNC-like modems use some ASCII codes for modem control. The PCI-4000 CLOVER modem does not have any restricted use codes - like Ctrl-C or any other in-line control code. This means that CLOVER can send text, executable computer files, computer programs, graphics, digitized voice, and even special data codes with no modification to the modem or your data stream.

Seventh, CLOVER is designed to have a very narrow frequency spectra. *All* CLOVER frequency components are contained within 500 Hz - down to -50 dB. In contrast, 100 baud AMTOR is 1000 Hz wide at -50 dB, 200 baud Pactor 1500 Hz wide, and AX.25 packet and G-TOR 2000 Hz wide at -50 dB. The actual measured frequency spectra of CLOVER-II, AMTOR, PACTOR, and 300 Bd FSK (G-TOR and HF Packet) are shown in Figures 2, 3, and 4.

Why be concerned with -50 dB instead of -3 dB, -6 dB, -20 dB or some other "bandwidth specification?" Suppose you are working a weak signal at S3 and another station comes on the air only a few Hz away - and he's running S9+10dB. If both are CLOVER signals, the interfering signal can be as close as 500 Hz away and you'll still copy the S3 guy. If the interference is running AMTOR, he must be 1 kHz away; Pactor, 1.5 kHz, and G-TOR and packet 2 kHz away! Who would *you* rather work around? Put another way, we can pack 20 CLOVER signals in 10 kHz but only 5 packet or G-TOR signals in the same bandwidth. Why be a "band-hog?"

Ok, Who needs CLOVER and why? You need CLOVER if you want three of the following five features:

- ¤ 1. Send data faster - by a multiple of 2 to 10 times.
- ¤ 2. Send full 8-bit, "transparent" data - text, computer files, images, whatever.
- ¤ 3. Send a signal that is bandwidth efficient - narrower by a factor of 2 to 4.
- ¤ 4. Be the first on your block to run "funny-sounding CLOVER tones."
- ¤ 5. Own the best (and most expensive) modem (yeah, we're working on the price).

Yes, there are choices you can make and not everyone will want or even need all features of all of the new modes. CLOVER is outstanding when you have a lot of traffic to pass. As TY1PS has demonstrated with his *EXPRESS* program, CLOVER also shines when you want to send very large files - such as computer programs, video images, and even digitized voice. At other times - like DX contests - plain old "steam RTTY" may be your best choice. The decision is up to you, the user. By the way - the fancy DSP hardware required to do CLOVER also does an outstanding job on the "other modes." The PCI-4000 is now a true "multimode" modem, including CLOVER *and* RTTY, AMTOR, and Pactor. If you'd like to know more about CLOVER, read the following articles - and give HAL a call.

RTTY Journal: April and May/June 1994; April, 1993; January, 1992; January through April, 1991. *Communications Quarterly*: Spring, 1992. *CQ*: May, 1992. *QST*: May, 1993. *QEX*: March, 1992; July, 1990. *ARRL Computer Networking Conference Proceedings*: #11 (1992); #10 (1991). *CQ-DL*: June, 1993 (in German). *CQ (Spain)*: November, 1992 (in Spanish). *SWISS ARTG Bulletin*: January, 1993 (in German).

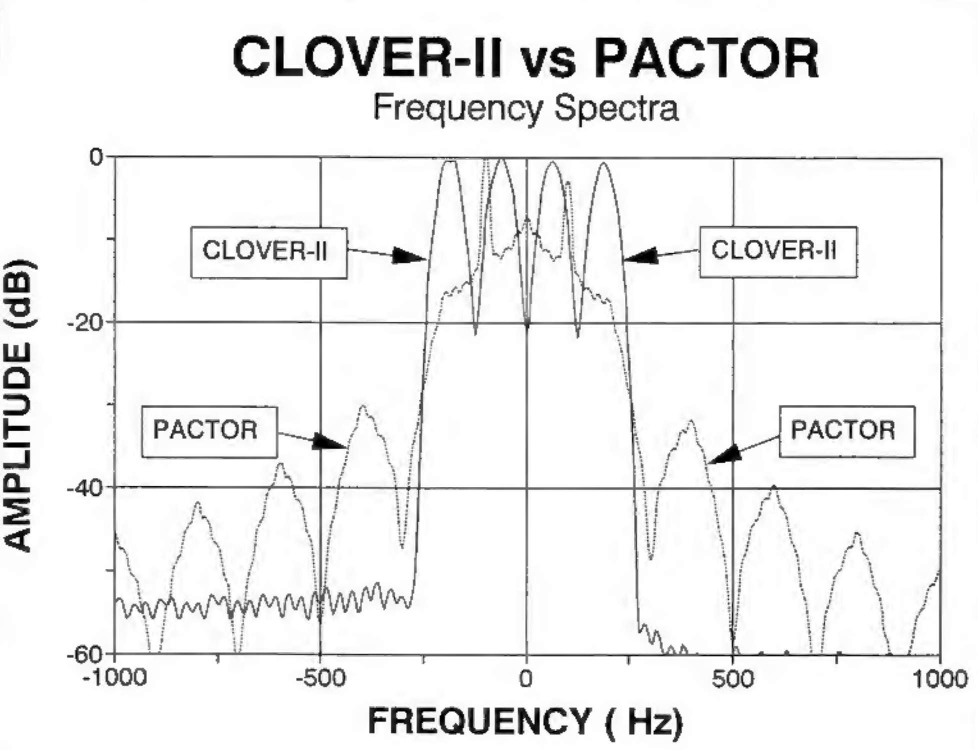

Figure 3

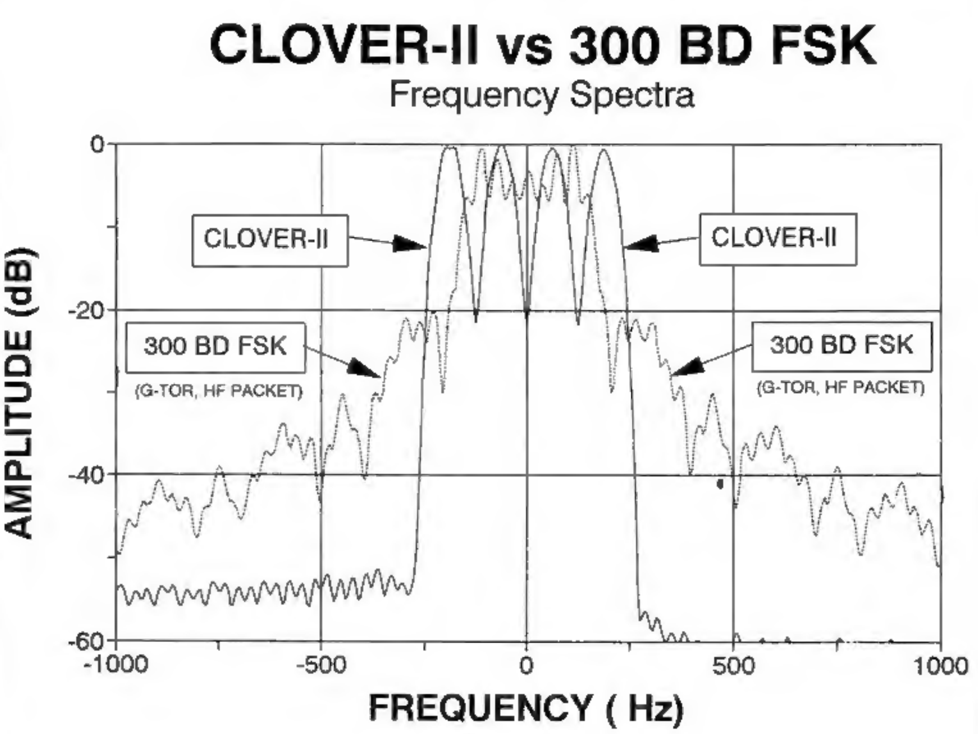

Figure 4

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† - Bill Henry, K9GWT, President, HAL Communications Corp. PO. BOX 365, Urbana, IL 61801-0365

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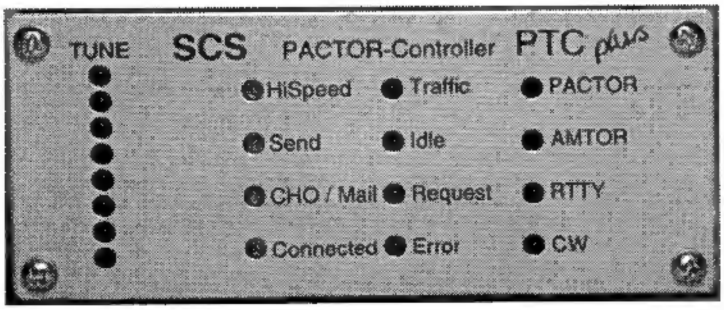

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G-TOR™: Epoch in Amateur HF Digital Communications

Phil Anderson, W0XI[†]

Over the past several years, many articles and editorials describing the deficiencies of current HF data communications protocols have been published. The central theme of the articles is that the protocols, the stated rules by which the particular modes operate, fall short of their promises because they fail to make use of modern signal-processing such as forward error correction (FEC) and data interleaving to combat noise and interference. Automatic repeat request (ARQ) systems such as AMTOR will be partially or totally disabled in the presence of strong interference from another digital signal. In fact, they will be reduced to continually repeating the same message over and over again.

As a result of the inefficiencies of the existing modes, Kantronics introduced G-TOR (Golay-TOR), the newest digital mode, in March 1994. G-TOR is an improved protocol for the exchange of data between HF stations. We wanted the mode to be easy to use, but we also designed G-TOR to operate with currently-existing multi-mode TNCs to keep the costs low. In addition, we included several unique features to aid in maintaining throughput in the presence of noise and interference. In light of the channel conditions that amateur radio operators encounter daily, such features are essential for fast, error-free operation. G-TOR's outstanding capabilities can be attributed to the combination of data interleaving, variable baud rate capability, ARQ with forward error correction (FEC) coding, and on demand data compression - together for the first time in an inexpensive stand-alone TNC, the KAM Plus.

Now, with all the advanced features of the latest modes, how should operators decide which mode to choose for efficient operation, and how can users determine which modes do a good job? Perhaps a good way to decide is to examine our needs as HF digital operators. Consider the typical band conditions and the common problems encountered, for instance. Additionally, we must consider what our goals are: to operate just for fun, to maximize throughput, or to simply explore the new modes. We can then evaluate the protocols and systems in light of our real needs. Obviously, arbitrary specifications of ionospheric activity just won't do.

Therefore, to combat the conditions we encounter daily, an ideal mode would need to filter out interference, reduce fading effects, and be able to dig signals out of the noise. It would also have to be terrific - able run at full speed - when band conditions are ideal! This is an important point of any mode. If a mode is designed to combat weak signals by adding extra bits or by retransmitting its message over and over again, the way AMTOR does, then the mode is very slow when the added bits are not necessary. A good protocol should allow for maximum transmission speeds when conditions allow. Finally, an ideal mode should be easy to use and low in cost!

As it turns out, the operating characteristics of G-TOR were designed to meet these not-so-abstract band conditions. G-TOR fights random and structured interference (another signal) by "chopping up" batches of bits in error and dispersing them throughout a frame. This process is called interleaving. With interleaving, the bits of each data character are dispersed across a data frame before transmission. Upon reception, the bits are rearranged, or de-interleaved. Figure 1 denotes the interleaving of data bits within a frame. De-interleaving upon reception disperses batch errors into single errors, enabling FEC to work. In other words, interleaving correction works best with random errors. Therefore, if a burst error occurs on the HF channel, due to fading or interference, the damage will be spread out into small pieces across the entire frame rather than mutilating large, non-recoverable sections. In this way, only one or two bits of a segment will be damaged, making the entire transmission easily recoverable

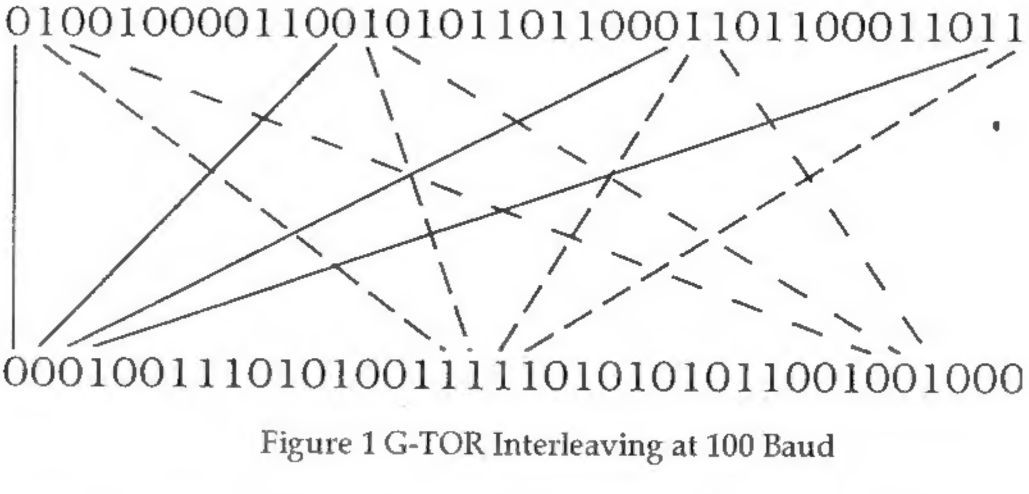

Figure 1 G-TOR Interleaving at 100 Baud

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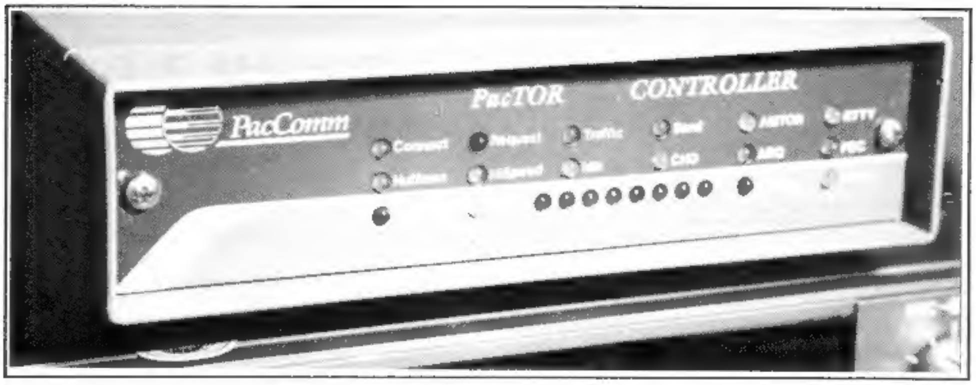

PacComm's PacTOR Controller

Reviews of PacComm's PacTOR Controller: (Call or write PacComm for a reprint). January 1993 **QST**, New Product Reviewand February 1993 **Ham Radio Today** (UK) November 1993 **RTTY Digital Journal**, page 18. "Review" by Phil Sussman, KB8LUJ March 1994 **QST**, page 67. "Plug into PacTOR".

PACTOR, PACTOR-II, CLOVER, G-TOR, Who knows what else!

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KAM Plus with G-TOR. Together, the two are taking HF digital communications by storm.

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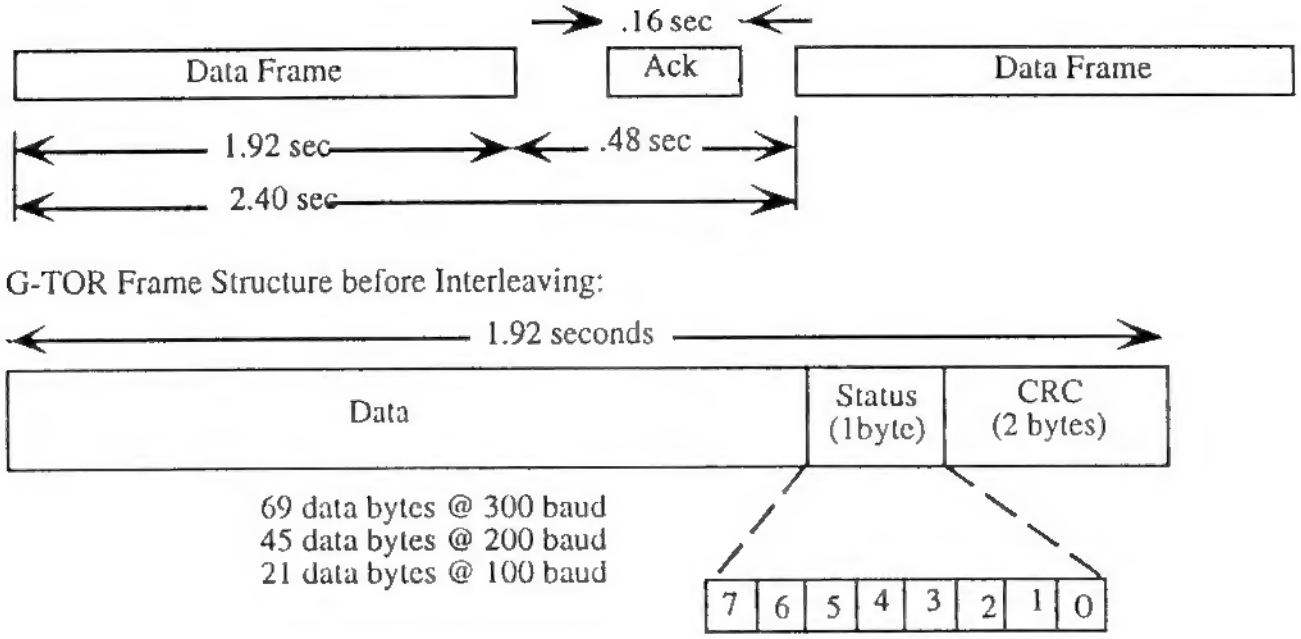

Figure 2 - G-TOR Frame Timing

with FEC (Golay) techniques. Of course, the usual packet CRC check is made to determine that all bits were indeed corrected.

When failures are due primarily to weak signals, FEC can correct most errors, thereby allowing the system to continue to operate at much higher bit error rates than conventional AMTOR like systems. However, if fading is severe and a frame of data cannot be fully corrected, G-TOR relies on it's variable baud rate capability (300, 200, or 100) to effectively maintain the link. Initially, G-TOR transfers data at 100 baud. If transfer proceeds smoothly, the baud rate increases to 300. In the event of persistent interference or poor band conditions, G-TOR will automatically adjust to 200 or 100 baud, whatever is optimal given the conditions. Of course, when conditions are ideal, G-TOR reduces overhead and dispenses with unnecessary retransmissions, thereby operating at the full transmission rate.

Regardless of transmission rate, the cycle duration is always 2.4 seconds. Data frames are 1.92 seconds long and the acknowledgements take 0.16 seconds. At 300 baud, each data frame contains 69 bytes of data, one control byte, and two CRC bytes. These are all aspects of the G-TOR ARQ cycle depicted in Figure 2. Thus, G-TOR operates as a synchronous mode, which means that each transmission is timed to occur at exactly the same intervals. This allows the receiver to anticipate the signal, making it more effective at capturing it. As a result, synchronous modes are more robust and can still work well with weaker signals.

Another benefit of synchronized data transmission is that unnecessary or redundant information can be eliminated from each frame and more bits can be dedicated to data rather than overhead. Frame efficiency, tabulated in Figure 3, results from the elimination of unnecessary starting and ending flags. Note that G-TOR, at 300 baud, has a frame efficiency of 95.8%.

Figure 4 displays the advantage of adding Golay FEC to the G-TOR ARQ cycle. Without FEC added, most frames would be received in error if the error rate of bits received exceeds one in one-thousand. By adding FEC capability, G-TOR systems can maintain one half rate throughput, with a much higher bit error rate. An added advantage, as noted before, is that with a combination of interleaving and FEC, G-TOR systems combat interference due to other digital signals too. Repetitive bursts, well-timed to take the center out of sequential AMTOR frames, don't effect G-TOR frames nearly as much.

In addition to detecting and correcting errors, we added data compression as an extra boost to the G-TOR protocol. G-TOR compresses data frames automatically providing higher throughput results. In addition, the data is coded automatically for upper case or lower case dominance. For example, if a message is typed in all upper case letters, G-TOR notes this and rearranges it's Huffman table to reduce the number of bits necessary to send your upper case message. In addition, the Huffman table ranks characters in terms of English rather than German character frequency as used in Pactor. If characters are repeated in a data frame, such as "––––," G-TOR makes note of that too and sends the character only once followed by a number indicating how many duplicates of the character must be printed at the receiving station. Such encoding is called run-length. Hence, in some instances, "screens" of boxes are transmitted at very high effective baud rates.

While all of these features combined together make G-TOR a very reliable and effective mode, ultimately G-TOR's success will be determined by its usage. Currently, well over 4,000 G-TOR based EPROMS have been shipped since its release in March, and since G-TOR is a standard feature in the popular KAM Plus and Enhancement Board for the KAM, many G-TOR stations exist worldwide. Suggested retail price for the KAM Plus is $339.95 and for a KAM Enhancement Board, $89.95. Those who own a KAM or KAM Plus without G-TOR capability may purchase an upgrade EPROM for just $39.95, making G-TOR a very cost-effective update.

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† - Phil Anderson, W0XI, President, Kantronics Co. Inc., 1202 E 23rd St, Lawrence, KS 66046-5006

Mode	Baud Rate	Data (bits/frame)	Frame efficiency	Cycle efficiency	Ideal bits/sec
AMTOR	100	15	71.4%	33.33%	33.3
PacTOR-LP	100	64	66.7%	45.71%	45.7
PacTOR-LP	200	160	83.3%	57.14%	114.3
PacTOR	100	64	66.7%	51.20%	51.2
PacTOR	200	160	83.3%	64.00%	128.0
G-TOR	100	168	87.5%	70.00%	70.0
G-TOR	200	360	93.8%	75.00%	150.0
G-TOR	300	552	95.8%	76.67%	230.0

Figure 3 - ARQ Frame Efficiencies

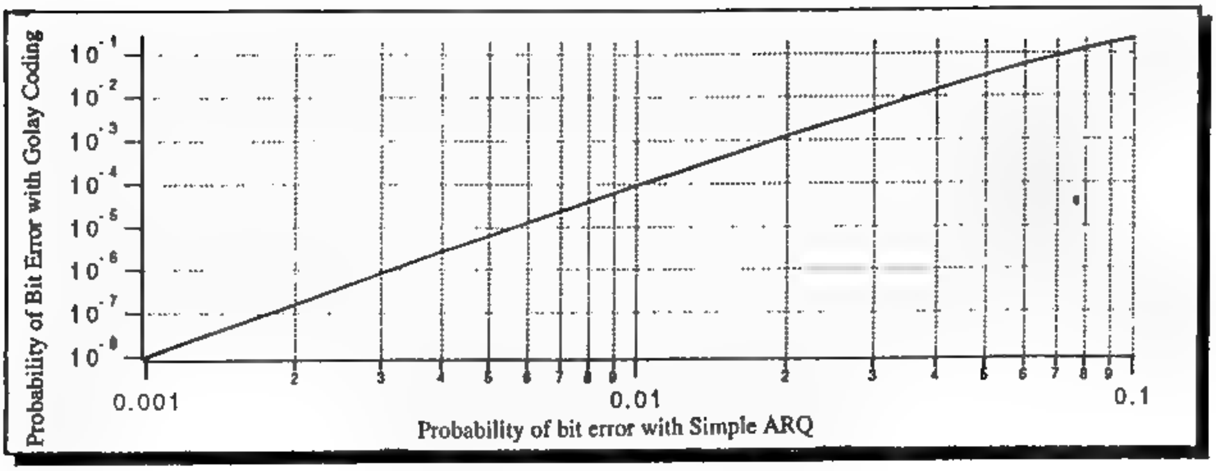


Figure 4 - G-TOR Error Correction Coding Gain

PACTOR

By Dr. Tom Rink, DL2FAK[†]

I. Introduction

PACTOR was first introduced to the Amateur Radio community in Germany early 1990 and is thus not really a new mode. Its name is derived from the corresponding Latin word, which means 'the mediator'. The system was developed by German Radio Amateurs specifically for short wave operation on poor quality channels, to overcome the known disadvantages of the existing digital modes used on short wave, such as AMTOR and Packet Radio. PACTOR was designed to provide almost the optimum throughput obtainable using an inexpensive FSK-System, within the bandwidth limit of 500 Hz. The protocol should also run on the usual cheap hardware and not require high processing power or expensive DSP equipment. For this reason, the wide-spread Z80 chip was chosen as the CPU for the first PACTOR-Controller (PTC), available at the German company 'SCS - Special Communications Systems'.

As PACTOR actually meets all the above mentioned requirements, it has gained great popularity within a very short time, causing other companies to add this mode to their existing units or build their own PTCs according to the German model.

In the meantime, the German developers licensed their PACTOR-Technology to seven other companies, among them leading manufacturers of multi mode-modems.

Nowadays almost every short wave modem available in the market includes PACTOR, even if the implementation is not a licensed one. Tens of thousands of Radio Amateurs are currently QRV in PACTOR and their number is still growing, thus it has already became a new world-standard. This distinguishes PACTOR from CLOVER and G-TOR, which are produced and promoted from just one single company each and therefore only used by a relatively small group of Radio Amateurs.

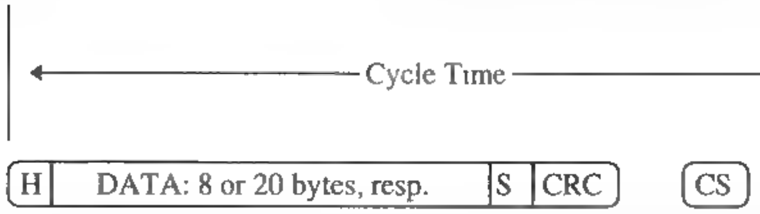
II. Short System Description

PACTOR is an improved half-duplex synchronous ARQ system, which does not only combine the reliability of Packet Radio with the fixed AMTOR time frame, but additionally includes new powerful features that had not been used in any digital mode of Amateur Radio before, among them adaptive transmission speed, on-line data compression and Memory-ARQ (see below).

The PACTOR frames consist of blocks (packets) containing data information. These are acknowledged by short control signals (CS) sent out by the receiving station. Shift levels are toggled with every cycle in order to support Memory-ARQ and make any 'mark/space'-conventions obsolete. The entire cycle duration is normally 1.25 seconds or 1.40 seconds in longpath-mode, which has first enabled an ARQ link over the long path due to a longer receiving gap. The standard timing is basically similar to AMTOR, i.e. all transceivers which allow AMTOR traffic can also be used for PACTOR operation without any modification. Additionally, the original SCS-PTC provides the option of changing the delay for the transmission of the data blocks (TXD) and control signals (CSD) in order to compensate slower switching within the given range of the time frame PACTOR allows the transfer of the complete 8-bit ASCII character set with an extremely low probability of undetected errors, due to the 16-bit CRC used as in Packet Radio. PACTOR is thus also suitable for true binary data transfer. The structure of the PACTOR frame is shown in Figure 1.

PACTOR automatically checks the channel quality and transfers data with 200 baud if the propagation conditions are good and switches down to 100 baud in bad conditions. Higher baud rates than 200 baud have been avoided on purpose in order to match the signal to the usual 500 Hz filters. With regard to 8-bit ASCII, the basic protocol transfers 8 or 20 data bytes per cycle at 100 or 200 baud, respectively

The on-line Huffman data compression, however, is normally switched on, which again improves the throughput considerably. The basic idea of the Huff-



H. Packet Header, required for synchronisation, Listen Mode, and Memory-ARQ
DATA: Arbitrary information (8bit/byte), CRC: 16-Bit CCITT Cyclic Redundancy Check
CS: Control Signals for ACK, NACK, speed-change, and changeover

S: Status Byte. Bit 0,1: modulo-4 packet number
Bit 2,3: data type, 00=ASCII, 10=Huffman, 01=swapped Huffman, 11=reserved
Bit 4,5: reserved
Bit 6,7: Changeover request, QRT Packet

Cycle Time: 1.25 or 1.4 sec (longpath option), respectively

Figure 1 - PACTOR frame structure

man-Algorithm is similar to the Morse code: frequent characters have short codes and rare characters have longer codes. Assuming average plain English text, this compression increases the throughput approximately by factor 1.5, hence leading to an effective speed of about 200 baud, which is already 5 times faster than AMTOR. Additionally, the firmware of the original SCS-PTC always calculates whether the Huffman coded packet or the plain ASCII packet is shorter and automatically transmits the shorter one. This is important, as it would otherwise be possible to lengthen the code and slow down the speed if only rare characters were transmitted.

Memory-ARQ is probably the most outstanding novelty of PACTOR. It is able to achieve a reasonable throughput in even such poor propagation conditions, that error correcting block codes, like Golay or Reed Solomon as used in newer digital modes, are not able to maintain the link. Also, Memory-ARQ requires far less processing power. The method is to sum up corresponding bit samples of subsequent packets until the mean value passes the CRC. The effective S/N ratio increases with each repetition and can be calculated as 10 times log(n), where n is the number of repetitions; i.e. 3 dB are gained after one repetition and 10 dB after 10 repetitions. Since the shift levels of the PACTOR signal are toggled with every transmission, this method does not only improve the throughput at a low S/N ratio but also clears off QRM and even constant interferring signals, like carriers, etc.

It is evident that Memory-ARQ can only work efficiently, if the bit samples represent the complete analog information of the signal strength rather than a simple 0/1 decision. This is the only way to distinguish whether the signal is e.g. 1 or 100 mV over the converter threshold. It does, however, require an analog to digital converter (ADC) in the hardware of the corresponding PACTOR modem. Unfortunately most PACTOR equipment does not include such an ADC and its weak signal performance is therefore far from optimum. Sometimes so-called 'digital Memory-ARQ' is used in modems without an ADC, which just means adding only the simple 0/1 information, as the software acts as an 1-bit ADC anyway. In this case at least half of the possible gain is sacrificed. PACTOR is the digital mode which still behaves best in weak signals, but you have to use a PTC (which includes an 8-bit ADC) or other hardware equipped with an ADC or even a DSP to take advantage of this feature. A comparison of the throughput with and without Memory-ARQ is shown in Figure 2.

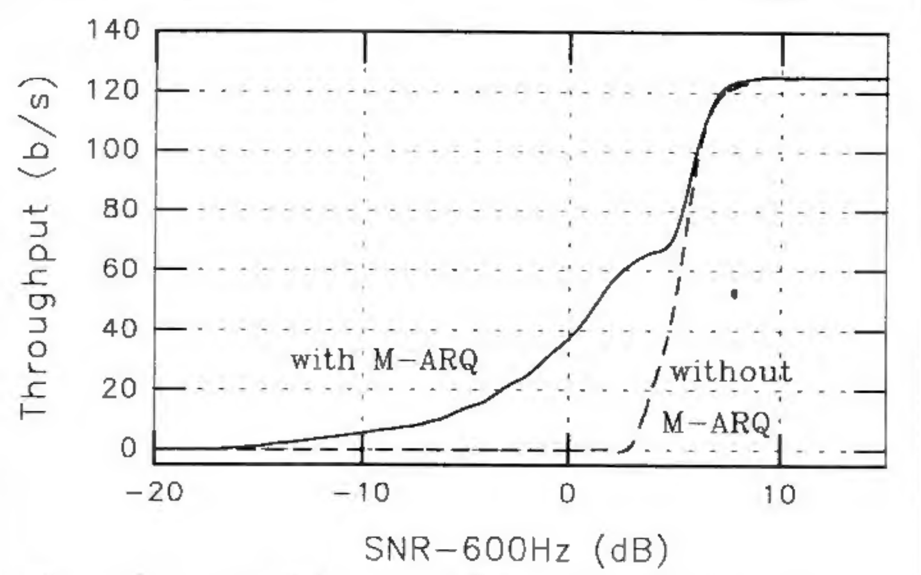


Figure 2 - Analog Memory - ARQ on AWGN - channel

A complete description of the PACTOR protocol is published in the AMTOR column of the RTTY Digital Journal, Volume 40, Number 6 (July/August 1991). Another protocol information as well as a description of the Z80-PTC can be found in Volume 116 (October 1991) of the ARRL Experimenters' Exchange 'QEX'.

III. Practical Aspects

Dale Sinner, W6IWO, wrote in his column 'Hits and Misses' of the RTTY Digital Journal, Volume 41, Number 6 (July/August 1993): 'If you have been listening on the bands of late then you have noticed the sudden increase in the use of PACTOR. Unlike most new toys and improvements we Hams have received over the years, I have never seen such excitement on the bands (except maybe when SSB was first introduced). PACTOR is everywhere and I am excited about this...'

As already mentioned above, actually tens of thousands of Radio Amateurs in more than 150 different DXCC countries are currently QRV in PACTOR and the number is still increasing. Johannes Chmielus, DJ1IJ, one of the most active PACTOR operators in Germany, managed to work 127 countries already in PACTOR up to June 1994. Numerous PACTOR mailboxes can be found on all bands and many of them provide access to the local VHF Packet Radio network or even link different continents via store and forward. What made PACTOR such a popular mode?

First of all, it is easy to use and well suited for direct contacts from operator to operator. Due to its short cycle duration, it enables the required fast and reliable change-over and break-in. This was already known and appreciated by the AMTOR users before. Additionally, it supports optimum adaptivity in rapidly changing band conditions, like multipath. Longer frames lower the flexibility of a system and also waste the transmission capability when only a few characters are transferred before the next change-over. The packets are therefore not filled up with data. This can always be observed in mailbox QSOs, where one direction is mainly used to transfer short command strings. In addition, it was the ability of transferring the complete ASCII character set virtually error-free over a short wave link, even in very poor propagation conditions, which really seemed to cause the success of PACTOR, as this was not possible with any previous mode, and not, as in popular opinion, just the higher maximum throughput.

Another item is the easy way to become QRV in PACTOR, since nearly all short wave modems in the market include the PACTOR mode anyway. Older units can usually be upgraded just by changing the EPROM which contains the firmware. However, upgraded units and most of the wide-spread 'all-purpose' modems are not capable of analog Memory-ARQ due to the missing ADC. There are also no special demands on the transceiver for PACTOR operation, as the signal passes the usual 500 Hz CW filters and does not require high stability of the frequency or faster switching than AMTOR. FSK as well as AFSK modes can be used in the same way like High- or Low-Tones. As terminal, any computer equipped with an RS-232 connector or even a simple V24-Terminal can be used. Special software is not required but, nevertheless, available for most PACTOR modems.

As all units have their own specialties, a typical PACTOR modem will be shortly described using the example of the original German SCS-PTC, now available as 'PTCplus' with a powerful 68000 CPU. A complete description of the unit was published in the RTTY Digital Journal, Volume 42, Number 2 (February 1994). Besides PACTOR, the unit also supports AMTOR, RTTY and CW operation. Due to the increased processing power, the PTCplus is able to be stand-by in PACTOR ARQ and Listen as well as in AMTOR ARQ and FEC at the same time. A comfortable built-in mailbox with up to 256k bytes memory (depending on the RAM size) is available from the PACTOR as well as from the AMTOR side simultaneously. The command structure of the PTC is similar to that of a TNC with TAPR firmware and therefore well-known by many operators that come from Packet Radio, making it very simple switching over to PACTOR. The installation is quite easy, as only the baud rate to the terminal has to be set by a coding switch at the rear panel of the unit. There are no jumpers inside the PTC, thus there is no need to open the case. After making the connections to the transceiver and the terminal, the unit is ready for operation. For PC users, a comfortable terminal software ('MT.EXE') is included, which simplifies the handling of the PTC. It provides pull-down menues and hot-keys for the most important functions, a multiple splitscreen, fix-files, an automatic log book and much more. There are several special features, e.g. a binary data transfer mode, which allows transfer of all kind of binary information, like *.EXE-Files, picture- and voice-files and any kind of compressed information. Each file is coded individually in order to make the resulting Huffman-Code as short as possible and thus apply an additional data compression. A detailed description of this binary mode can be found in the PACTOR column of the RTTY Digital Journal, Volume 42, Number 1 (January 1994).

There is also quite a lot of mailbox software available for those who want to set up a bigger mailbox with an external computer. Most of it is available for free. As BBS software is created by numerous people in all continents and for all kinds of modems and computers, there is no-one who has a full survey of all existing programmes. The following brief description will therefore be limited to three boxes for the PC, which are probably most wide-spread at the moment.

JA3FJ added a PACTOR port to the G3PLX software. This modified version requires a PTC for PACTOR operation and different modems for the AMTOR and the Packet Radio port. The software is also capable of automatic store and forward via PACTOR on short wave. For this option the channel-busy flag of the PTC status word, which supplies the information whether there is any traffic on the short wave channel, is used by the software in order not to disturb any other QSOs with automatic data exchange. This software is mainly used in Asia and Europe. It is available at 9M2CR, who has taken over the distribution, for JA3FJ. The 'KCQ-MBX', written by W8KCQ, provides a common AMTOR and PACTOR box by using the AMTOR side of the PTC as well, thus no additional modem is required. 'Winlink' by K4CJX does not work with a PTC but requires a PK-232, which is not capable of analog Memory-ARQ. It is mainly used in the US and also provides a store and forward option for the short wave side.

IV. Considerations for the Future

With regard to the basic requirements of each digital mode (like throughput, bandwidth, error rate, etc.) PACTOR already represents nearly the optimum attributes obtainable with usual 2-tone FSK systems. A considerable increase of the throughput can only be done by increasing the baud rate (which also means increasing the bandwidth) or lengthening the packets (which leads to longer respond times and reduces the adaptivity of a system). In FSK systems, error correcting codes and the obligatory interleaving may be applied when longer packets are used, to avoid a repetition when only a few bits are erroneous. However, they can neither really improve the link quality in borderline propagation conditions with very low S/N ratio, nor increase the maximum throughput in good conditions. In modes with a short cycle duration, a repetition can be accepted without an appreciable loss of throughput. Additionally, analog Memory-ARQ, as used in PACTOR, already goes beyond the limits of the usual error correcting codes. Information can be accumulated from bit samples of many corresponding packets in a row, rather than just using the original data and the information of the corresponding coded parity.

This reflection leads to the conclusion that we have to use modulation schemes different from FSK, if we want to gain higher effective baud rates without increasing the bandwidth. A powerful solution is to apply Phase Shift Keying (PSK). The more different phase shift levels that can be distinguished, the higher is the maximum throughput. Additionally, amplitude modulation of the PSK signal may be used to achieve a still higher throughput. All these ideas have already been taken into consideration with the invention of CLOVER.

Not only the maximum throughput should be inproved however, but also the weak signal performance. This can be done using a combination of Memory-ARQ with powerful convolutional coding. In addition, there should not be too high a demand placed on the transceiver used regarding its frequency adjustment and stability.

PACTOR-II, which will come on the market later this year, meets all these requirements. The maximum speed of the current protocol is 800 bits per second and is obtained using a 2-tone 100 baud D-QPSK (4-PSK) and 4-ASK signal. The on-line Huffman data compression, as already used in the current PACTOR level, further increases the throughput, thus leading to an effective maximum speed of more than 1200 bits per second. Apart from the usual Memory-ARQ, Viterbi-Decoding is applied, which is able to provide an additional improvement of the link quality even in very poor conditions. Of course PACTOR-II is backwards compatible to the current protocol level, hence there will be no problem to find a QSO partner.

As this kind of coding requires a lot of processing power, the PTC-II features a 68360 CPU clocked with 25 MHz and a DSP 56156 running at 40 MHz. In addition, a SIMM socket is provided which allows up to 32 MB of dynamic RAM to be inserted for optimum decoding. Further, the PTC-II may contain up to 2 MB of static RAM for the built-in mailbox. A complete description of the unit will be published in due course. Although the PTC-II will be the most powerful unit in the market, its price is planned to be only around 950$.

Nevertheless, the PACTOR-II protocol is designed also to be demodulated by less powerful hardware, in order to allow the implementation in cheaper DSP modems as well, similar to the current PACTOR implementations in units without an ADC or even without any Memory-ARQ. This could for example be done by shortening the constraint length of the PACTOR-II code, which of course again means sacrificing a considerable part of the weak signal performance.

† - Dr. Thomas Rink, DL2FAK, General Manager, SCS, Rontgenstrabe 36, D-63454, Hanau, Germany

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